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XXVII. *Some Experiments on the Combustion of the Diamond and other carbonaceous Substances.* By Sir Humphry Davy, LL.D. F. R. S. V. P. R. I.

Read June 23, 1814.

SINCE it has been shewn by various accurate experiments, that the diamond and common carbonaceous substances consume nearly the same quantity of oxygene in combustion, and produce a gas having the same obvious qualities, a number of conjectures have been formed to explain the remarkable differences in the sensible qualities of these bodies, by supposing some minute difference in their chemical composition; these conjectures have been often discussed, it will not be necessary therefore to dwell upon them: M. M. BIOT and ARAGO, from the high refractive power of the diamond, have supposed that it may contain hydrogene; I ventured to suggest in my third Bakerian Lecture, from the circumstance of its non-conducting power, and from the action of potassium upon it, that a minute portion of oxygene may exist in it; and in my Account of some new experiments on the fluoric Compounds,* I hazarded the idea that it might be the carbonaceous principle combined with some new light and subtile element of the class of supporters of combustion. M. GUYTON DE MORVEAU, who conceived he had proved by experiments made fourteen years ago, that common carbonaceous substances were oxides of diamonds, from his last researches, conducted in the same manner as those of Messrs.

* Phil. Trans. for 1814. Part I, p. 72.

ALLEN and PEPYS, seems still inclined to adopt this opinion, though in admitting a much smaller quantity of oxygene than he originally supposed in charcoal; and he considers the diamond as pure carbonaceous matter, containing, possibly, some atoms of water of crystallisation.

I have long had a desire of making some new experiments on the combustion of the diamond and other carbonaceous substances, and this desire was increased by the new facts ascertained with respect to iodine, which by uniting to hydrogen, affords an acid so analogous to muriatic acid, that it was for some time confounded with that substance. My object in these experiments, was to examine minutely whether any peculiar matter was separated from the diamond during its combustion, and to determine whether the gas, formed in this process, was precisely the same in its minute chemical nature, as that formed in the combustion of common charcoal. I have lately been able to accomplish my wishes; I shall now have the honour of communicating my results to the Royal Society.

During a stay that I made at Florence in the end of March and beginning of April, I made several experiments on the combustion of the diamond, and of plumbago, by means of the great lens in the Cabinet of Natural History; the same instrument as that employed in the first trials on the action of the solar heat on the diamond, instituted by Cosmo III. Grand Duke of Tuscany; and I have since made a series of researches on the combustion of different kinds of charcoal at Rome, in the laboratory of the Academia Lyncei. In the first series I was honoured by the assistance of the Count BARDI, the Director, and Signior GAZZARI, the Professor of Chemistry at the

Florentine Museum; and in the last by that of Sig. MORRICINI and BARLOCCI, Professors of the College Sapienza at Rome.

In the very first trials on the combustion of the diamond, I ascertained a circumstance that I believe has not been noticed before; namely, that the diamond, when strongly ignited by the lens in a thin capsule of platinum perforated with many orifices, so as to admit a free circulation of air, continues to burn in oxygene gas after being withdrawn from the focus. The light it affords is steady, and of so brilliant a red, as to be visible in the brightest sunshine; and the heat produced is so great, that in one experiment, in which three fragments of diamonds weighing 1.84 grain only were burnt, a fine wire of platinum used for attaching them to the tray was fused, and that some time after the diamonds were removed out of the focus.

The knowledge of this circumstance enabled me to adopt a very simple apparatus and mode of operation in my researches, and to complete, in a few minutes, experiments which have been supposed to require the presence of a bright sunshine for many hours.

My apparatus consisted of clear glass globes of the capacity of from fourteen to forty cubical inches, having single apertures to which stop-cocks were attached; a small hollow cylinder of platinum, which I use in experiments with the blow pipe, was attached to one end of the stop-cock, and was mounted with a little perforated capsule of platinum for containing the diamond. When the experiment was to be made, the globe containing the capsule and the substance to be burned was exhausted by an excellent air pump, and pure oxygene gas, made from hyperoxymuriate of potassa, admitted. The globe

before and after the experiment was brought to the same temperature as the water over which the oxygene gas had remained. And as during the short time required for the combustion there was no sensible change either in the thermometer or barometer, no corrections for pressure or temperature were rendered necessary; the change of volume in the gas after the combustion, was estimated by means of a fine tube connected with a stop-cock, adapted by a proper screw to the stop-cock of the globe, and the absorption was judged of by the quantity of mercury that entered the tube, which afforded a measure so exact that no alteration, however minute, could be overlooked. As the elastic force of the vapour of water is the same at the same temperature, it was evident, that if any water formed in these experiments, it would be deposited as dew or mist in the globe; and I am convinced by direct trials, that a quantity of moisture not capable of being weighed by a balance sensible to the $\frac{1}{100}$ of a grain, is rendered evident by deposition on a polished glass surface.*

The diamonds were always heated to redness before they were introduced into the capsule.

During the combustion of the diamond, the glass globe was kept cool by the application of water to that part of it immediately above the capsule, and where the heat was greatest.

In the first experiment, three diamonds, weighing together 1.63 grain, were entirely consumed, in a quantity of oxygene

• A piece of paper weighing a grain was introduced into a tube of about the capacity of four cubical inches, the exterior of which was gently heated by a candle; immediately a slight dew was perceptible in the interior of the upper part of the tube; the paper taken out and weighed immediately in the balance above referred to, had not suffered any appreciable diminution.

gas, more than three times as much as was necessary to convert them into carbonic acid. In this case, after the combustion had once commenced, it continued without a fresh application of the lens till there remained only a very thin piece of the largest diamond in contact with the capsule, and this by being brought into the focus, rapidly disappeared. On restoring the globe to its original temperature, there was a very evident deposition of moisture ; but on arranging the apparatus, so as to ascertain the change of volume of the gas, there entered only twenty-one grains of mercury. In this experiment, the cylinder of platinum had been fastened into the stop-cock by means of a small perforated cork ; it seemed probable, when the small diminution of gas was considered, that the appearance of moisture might be owing to the production of vapour from this cork during the combustion, and the second experiment demonstrated that this was the case.

In this second experiment 1.84 grains of small diamonds were employed, and a glass globe of the capacity of 14.9 cubical inches. Soon after the capsule was placed in the focus in bright sunshine, the diamonds burnt with great brilliancy, and continued to burn till they had considerably diminished in bulk ; but their splendour of combustion gradually became less, and before they had apparently lost half of their volume the process ceased. By placing them a second time in the focus, after agitating the globe so as to change their places, the combustion was again produced ; but the light was much less vivid than before, and the combustion continued for a much shorter time. They were exposed to the concentrated rays a third and a fourth time, but after the fourth time they seemed incapable of burning, and though kept for some

minutes in the focus, appeared to undergo no further diminution: two fragments remained, which, as it was afterwards found, weighed .52 of a grain; the barometer during the experiment was at 29.9 inches, the thermometer at 56° FAHRENHEIT. When the original temperature of the globe was restored, there was not the slightest appearance of vapour or humidity; the interior was as clear as before the experiment, and there was no solid matter of any kind separated in the tray. The fragments of diamond which remained were not black, but had lost their lustre like glass that has been acted on by fluoric acid, nor at any period of the process was any carbonaceous appearance perceived upon them. When the communication was made by the stop-cock between the interior of the globe and a surface of mercury, a minute quantity entered equal to 1.5 grain only.

A portion of the gas in the globe was transferred into a tube in the mercurial apparatus, and the oxygene it contained absorbed by the combustion of phosphorus; 3.5 parts of gas heated in this way left a residuum of 2.5 parts. A portion of the gas was agitated with lime water, when seven parts out of ten were absorbed. I exposed the gas which remained after the combustion of phosphorus to several tests; it had not only the obvious characters of carbonic acid, but exhibited exactly the same chemical phenomena. Potassium strongly heated in it in a small glass tube over mercury, burnt with a dull red light, and formed an alkaline product of the same intense black colour as that produced by its combustion in the carbonic acid procured by the dissolution of marble: distilled water absorbed rather less than its own volume of the gas, and became subacid, sparkled by agitation, gained the taste and smell

of a solution of carbonic acid in water, precipitated in the same manner lime water, and when in excess redissolved the precipitate. To ascertain if this precipitate was exactly the same in composition as pure carbonate of lime, I made a sufficient quantity of it by pouring lime water into the recipient containing the results of the first experiment; and after collecting and drying it at the temperature of 212° FAHRENHEIT, I introduced a quantity of it contained in some foil of platinum through mercury into a glass tube filled with mercury, and I heated in the same manner an equal quantity of finely powdered Carrara marble, and admitted to them equal quantities of solution of muriatic acid. In this trial, there was rather more elastic fluid disengaged from the Carrara marble than from the carbonate of lime from the diamond; but on examining the foil of platinum after the experiment, I found that a little of the carbonate had not been acted upon: I tried two similar experiments, substituting bibulous paper instead of the metallic foils for infolding the carbonates; the results were such as to shew that both substances afforded the same quantities of elastic fluid.

I heated some of the carbonate from the diamond in a tube which contained potassium, and passed the potassium through it in vapour: there was ignition, and a substance of a dense black colour was formed; this substance was acted on by dilute muriatic acid, when it left a fine black powder which burnt like lamp black, and when thrown into fused nitre scintillated and disappeared in the same manner as powdered charcoal.

The gas that remained in the second experiment, after the absorption of the carbonic acid gas, vividly supported combustion, and diminished with nitrous gas; but as the degree of

purity of the oxygene gas with which the globe was filled had not been determined before the experiment, it was impossible to ascertain with precision, that no elastic matter had been emitted during the process. To determine this point, I made a third experiment. A thin diamond weighing .93 of a grain was introduced into the platinum capsule, which was placed in a globe filled with water and inverted in water, some oxygene gas, the last portion from the decomposition of hyperoxymuriate of potassa, was thrown into the globe, so as to displace the water below the level of the capsule. The focus of the great lens was thrown upon the capsule, which with the diamond was instantly rendered dry by it, and the diamond soon entered into combustion and burnt as usual. After the process was finished, the carbonic acid was absorbed by lime water, and the remaining gas, which equalled about one-third of the quantity of oxygene originally used, was compared analytically in several experiments with a portion of the same oxygene as that introduced into the globe, two measures of nitrous gas being added to a measure of each of the gases; the diminution was less by from $\frac{1}{100}$ to $\frac{2}{100}$ parts in the cases in which the gas that had been exposed to the action of the diamond was used; but this minute difference is what might have been expected, and which indeed could not fail to exist, when it is considered that, during the absorption of carbonic acid gas by water and lime water, a small quantity of common air is always expelled from the water.

In this last experiment a small fragment of diamond remained unconsumed, which was similar in appearance to that mentioned in the second experiment, and its colour, which was originally yellow, was rendered rather darker. In no one of

the three experiments was there any distinct appearance of carbonization, when the process was stopped in consequence of the impurity of the gas; though the diamonds were of various colours and different lustres.

A piece of plumbago from Borrowdale in Cumberland, weighing two grains, was exposed in the focus in the same manner as the diamond in the first and second experiments, having been previously heated red; the quantity of oxygene gas employed was 8.5 cubical inches: more than half the plumbago remained unconsumed, and during the combustion some brown ashes were produced. The phenomena in this experiment were very different from those observed in the experiments on the diamond, the gas became clouded during the process, and there was a considerable deposition of dew on the interior of the globe. When the original temperature of the globe was restored, and the stop-cock opened, 96.6 grains of mercury entered, and drops of moisture even were observed condensed on the sides of the vessel.

In the second series of experiments, charcoal formed by the action of sulphuric acid on oil of turpentine, and some produced during the formation of sulphuric ether, from which nitric acid had been distilled, and which afterwards had been strongly ignited, and charcoal of oak which had undergone the same process, were used.

Three grains of the charcoal from turpentine were employed, 2.5 of that from alcohol, and five grains of the charcoal of the oak: in all these instances of combustion the gas became clouded during the combustion, and when the original temperature of the globe was restored, moisture was found condensed in the interior; much the largest quantity in the

experiment on the charcoal of oak, and the least in that on the charcoal procured from oil of turpentine. The charcoal from oak left a residuum of white ashes, which was principally carbonate of lime; that from oil of turpentine produced no residuum; that from alcohol, which was formed in a common process of the manufacture of ether, left a minute quantity of ashes, probably owing to the impurity of the sulphuric acid employed.

The quantity of mercury which entered the apparatus indicating the change of volume of the gas, was in the experiment on the charcoal of oil of turpentine - 107.5 grains

In that on the charcoal of alcohol - 194.5

In that on the charcoal of oak - 513.3

From the results of these different experiments, it appears evident, that the diamond affords no other substance by its combustion than pure carbonic acid gas; and that the process is merely a solution of diamond in oxygene, without any change in the volume of the gas; for the slight absorption in the second experiment is scarcely more than a compensation for the volume occupied by the diamonds consumed.

It is likewise evident that in the combustion of the different kinds of charcoal, water is produced; and from the diminution of the volume of the gas, there is every reason to believe, that the water is formed by the combustion of hydrogen existing in the charcoal, and experiments which I have referred to, or detailed in my third Bakerian Lecture, prove the presence of hydrogen in common charcoal, and as the charcoal from the oil of turpentine left no residuum, no other cause but the presence of hydrogen can be assigned for the diminution occasioned in the volume of the gas during its combustion.

M. GUYTON DE MORVEAU* has noticed the production of water during the combustion of plumbago from Keswick, and from these experiments it is most probable, that it is formed in the process of combustion, for it is unlikely that water should remain in union with plumbago at a red heat; and in the various experiments that I have made on the ignition of plumbago by Voltaic electricity, I have never perceived the separation of any moisture, or the production of any gas; so that it seems most likely that it contains intimately combined hydrogen. It cannot be supposed that water exists in it in union with oxide of iron, for in this case, there would be no obvious cause for the diminution of the volume of the gas; and all analogy is in favour of the conclusion that the iron is in a metallic state.

The general tenor of the results of these experiments is opposed to the opinion, that common carbonaceous substances differ from the diamond by containing oxygen; for in this case they ought to increase and not diminish the volume of oxygen: nor, on the other hand, is it favourable to the supposition that the diamond contains oxygen, for the difference in the quantity of carbonic acid produced in the different experiments, is no more than may be reasonably ascribed to the generation of water, in the combustion of the common carbonaceous substances; and the results of the experiments, to which I have referred in the beginning of this Paper on the action of potassium on the diamond, may be easily accounted for from other circumstances.†

* *Annales de Chimie*, Tome LXXXIV. page 241.

† See Bakerian Lecture for 1808. Potassium decomposes the silica in glass by being heated in contact with it, and in the case in which equal quantities of potassium

That charcoal is more inflammable than the diamond may be explained from the looseness of its texture, and from the hydrogen it contains; but the diamond appears to burn in oxygen with as much facility as plumbago, so that at least one distinction supposed to exist between the diamond and common carbonaceous substances is done away by these researches.

A fact which I formerly noticed, the blackening of diamond by the long continued action of heated potassium, induced me to suspect in the beginning of these inquiries, that common charcoal might owe its colour, opacity, and conducting power, to the circumstance of its containing minute portions of the metals of the alkalies, or earths, and plumbago to the iron it contains; but when I found that charcoal made from oil of turpentine, which left no residuum in burning, and charcoal precipitated from carburetted hydrogen gas by chlorine, had the same properties, it was necessary to renounce this opinion.

The only chemical difference perceptible between diamond and the purest charcoal, is that the last contains a minute portion of hydrogen; but can a quantity of an element, less in some cases than $\frac{1}{50000}$ part of the weight of the substance, occasion so great a difference in physical and chemical characters? This is possible, yet it is contrary to analogy, and I am more inclined to adopt the opinion of Mr. TENNANT, that the difference depends upon crystallization. Transparent solid bodies are in general non-conductors of electricity, and it is

were long heated in glass tubes, the one in contact with diamonds, the other alone, that in contact with the diamonds must have acted upon a much greater surface of glass.

probable that the same corpuscular arrangements which give to matter the power of transmitting and polarizing light, are likewise connected with its relations to electricity; and water, the hydrates of the alkalies, and a number of other bodies which are conductors of electricity when fluid, become non-conductors in their crystallized form.

The power possessed by certain carbonaceous substances of absorbing gases, and separating colouring matters from fluids, is probably mechanical and dependent upon their porous nature; for it belongs in the highest degree to vegetable and animal charcoal, and it does not exist in plumbago, coke, or anthracolite.

The same conclusions respecting the composition of carbonic acid may be drawn from these experiments, as from those of Messrs. ALLEN and PEPYS, and THEODORE DE SAUSSURE. If the calculations be founded upon the difference of the weights of oxygene and carbonic acid gases, which appears the most exact method, carbonic acid gas will contain, according to the estimate of the mean specific of the gravities of the two gases given by M. THEODORE DE SAUSSURE,* thirty parts of oxygene, or two definite proportions, to 11.3 parts of carbon, or one definite proportion.

Supposing the diminution of the oxygene produced in the experiments on the common carbonaceous substances entirely occasioned by the formation of water, it is easy to calculate the proportions of hydrogen in them; but in the case of plumbago there is probably a diminution of oxygene, from the oxidation of the iron; and it is not certain that the ashes

* *Annales de Chimie*, Tome LXXI. pag. 261. This estimation is the same as that I have given. *Elements of Chem. Phil.* pag. 305.

afforded by the charcoal from vegetable substances exist in it in the state of earths and alkalies: and as the quantity of hydrogen varies according to the degree of heat to which charcoal has been exposed, it is almost useless to attempt to assign its proportion in any particular case, especially when the largest portion is so extremely minute.

The nature of the chemical difference between the diamond and other carbonaceous substances may be demonstrated by another process, namely, igniting them in chlorine; when common well burnt charcoal, or plumbago from Cumberland, is intensely ignited in chlorine, white fumes are immediately perceived in consequence of the production of muriatic acid gas by the hydrogen, which acid precipitates the aqueous vapour in the chlorine; but the diamond occasions no such effect. A small diamond, weighing .45 of a grain, was kept in a state of intense ignition by the great lens of the Florentine Museum for more than half an hour, but the gas suffered no change, and the diamond had undergone no diminution of weight, and was not altered in appearance.

Charcoal, after being intensely ignited in chlorine, is not altered in its conducting power, or colour; and this circumstance is in favour of the opinion, that the minute quantity of hydrogen is not the cause of the great difference between the physical properties of the diamond and charcoal.